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Study on Utilization of Waste Heat in Cement Plant

Yuting Tan[a,b], Xun Li[a], Li Zhao[a,*], Hailong Li[b], Jinyue Yan[b,c], Zhixin Yu[d]

[a]*Key Laboratory of Efficient Utilization of Low and Medium Grade Energy, MOE, Tianjin University, 300072 Tianjin, PR China*
[b]*Department of Chemical Engineering, Royal Institute of Technology, SE 100 44 Stockholm, Sweden*
[c]*School of Sustainable Development of Society and Technology, Malardalen University, SE 721 23 Västrås, Sweden*
[d]*Department of Petroleum Engineering, University of Stavanger, 4036, Stavanger, Norway*

Abstract

This paper discusses three options for waste heat recovery in cement plant, they are dual-pressure power generation system, post-combustion capture system using MEA and the combined one. Model of power generation system was developed. Technical analysis was made from aspects of power generating capacity and CO_2 capture ratio. In addition, economic evaluation was conducted to assess the performance of three systems targeting on higher Net Present Value (NPV). Variation of economic parameters were considered like carbon credit (10-90 $ /ton) and price of electricity (0.06-0.18 $ /kWh). Optimal option can be selected for waste heat utilization based on economic evaluation results in this paper.

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Keywords: Cement Plant, Waste Heat Recovery, Carbon Capture,Power Generation

1. Introduction

Carbon Capture and Storage (CCS) and energy efficiency improvement have the biggest potential contribution to reducing greenhouse gas emissions [1]. Large amount of waste heat in cement plant can be recovered to reduce the energy consumption in cement production process. Technologies of waste heat recovery for power generation have been widely applied in the cement industry, including single-pressure steam cycle, dual-pressure steam cycle, organic Rankine cycle (ORC) and Kalina cycle. In addition, the cement industry represents a potential opportunity for CO_2 capture because of the high CO_2 concentration of flue gas [2]. Waste heat from flue gas can be also recovered to provide the energy demand of the carbon capture process, for example, MEA-based chemical absorption.

This paper compares three different options of using waste heat in cement plant from technical and economic aspects.

2. Options for Waste Heat Recovery

* Corresponding author. Tel.: +86-22-27404188; fax: +86-22-27404188.
E-mail address: jons@tju.edu.cn

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Case 1: power generation

In this option, waste heat of flue gas is used to generate high-temperature steam (H-T steam) and low-temperature steam (L-T steam) in the suspension preheater and air quenching cooler respectively.

Case 2: carbon capture

In this option, waste heat is used to support the heat demand of reboiler for carbon capture.

Case 3: power generation combined with carbon capture.

In this option, waste heat is used for both power generation and carbon capture. It is different from Case 1, L-T steam and the steam extracted from turbine at 4 bar are used to support the heat demand of reboiler.

3. Technical Analysis

3.1. Modeling of dual-pressure steam cycle

Energy balance is calculated as the equation. q is mass flow rate of steam, H is enthalpy, T is temperature, C_p and Q are heat capacity and mass flow rate of flue gas, i is inlet, y is flue gas, o is outlet.

$$q \times (H_o - H_i) = Q \times Cp_y \times (T_{y,i} - T_{y,o}) \quad (1)$$

3.2. Heat duty of Reboiler

The following equation is used to predict the heat duty of reboiler (Q_r) [3], where y_{CO2} is CO_2 mole concentration in percentage:

$$Q_r = 3.3162 + 0.0154 y_{CO_2} + 2.0383 / y_{CO_2} + 2.1432 / (y_{CO_2})^2 \quad \text{(MJ/kg CO}_2\text{)} \quad (2)$$

3.3. Input data and assumptions

Table 1 illustrates some key parameters of flue gas [4,5] and power generation system.

Table 1. Parameters of flue gas and cement plant

Parameter	Value	Parameters	Value
SP flue gas T and V / (ºC, m^3/h)	380, 350000	Turbine inlet T and P / (ºC, MPa)	315, 1.35
AQC flue gas T and V / (ºC, m^3/h)	340, 230000	Turbine exit pressure / MPa	0.1
CO_2 emission /(kt/yr)	728.4	Turbine extract pressure / MPa	0.4
CO_2 mole fraction /%	22.4	L-T steam T and P / (ºC, MPa)	160, 0.4
MEA / wt%	30	Turbine isentropic efficiency / %	80

3.4. Simulation results

Table 2. Parameters in three different systems

Parameter	Case 1	Case 2	Case 3
Power capacity /MW	6.64	N/A	4.24
Heat for reboiler /MW	N/A	34.15	25.52
Carbon capture ratio /%	N/A	35.6	26.6
CO_2 captured /(kt/yr)	N/A	259.3	186.5

Table 2 shows some simulation and calculation results of three cases, case 3 has the highest power capacity while case 3 has the biggest carbon capture capacity.

4. Economic Evaluation

4.1. Evaluation method

NPV is a central tool in discounted cash flow analysis and is a standard method for using the time value of money to appraise long-term projects. Here *P* is profit, *O* for operating cost, *C* is initial investment, i_c stands for discount rate.

$$NPV = \sum_{j=1}^{Y} \frac{P_j - O_j}{(1+i_c)^j} - C \tag{3}$$

4.2. Economic data

Table 3 gives the initial investment and operating cost of both CCS and power generation (PG) systems [5, 6]. Project life is set as 20 years, operation time is 7920 hr/yr, and i_c is 0.06. Payback time and NPV is calculated when price of electricity (P_e) is 0.06 \$/kWh and carbon credit (P_c) is 10 \$/ton

Table 3. Economic parameters in three different systems

Parameter	Case 1	Case 2	Case 3
Initial investment CCS /k \$	N/A	19093	15877
Operating cost CCS / k \$	N/A	12212	9570
Initial investment PG /k \$	9692	N/A	9692
Operating cost PG / k \$	1405	N/A	1405
Payback time / (yr)	5.5	N/A	N/A
NPV / m \$	749	-114	-95

4.3. Sensitivity study

Economic performance have been estimated with variation of P_e (0.06-0.18 \$/kWh) and P_c (10-90 \$/ton). Fig.1 illustrate the value of NPV and comparison between 3 systems, as shown in Fig.1, power generation system (case 1) has better economic performance when carbon credit is lower than certain value (58, 62, 71, 78, 80 \$/ton respectively for P_e= 0.06, 0.09, 0.12, 0.15, 0.18 \$/kWh). When carbon credit is higher, carbon capture system (case 2) and combined system (case 3) are optimal options for waste heat recovery in cement plant, specifically, when carbon credit keeps at low value (lower than 38, 50, 63, 80, 90 \$/ton respectively for P_e= 0.06, 0.09, 0.12, 0.15, 0.18 \$/kWh), case 3 is better option for its high profit from electricity. Case 2 is more sensitive to increment of carbon credit because it has higher carbon capture ratio, and case 2 has better economic performance when carbon credit is increased at higher value.

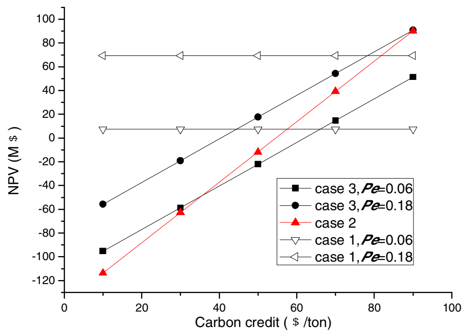

Fig.2 Economic comparison between three systems

5. Conclusion

This paper compares three different cases of waste heat utilization in cement plant. Power generation system (case 1) has better economic performance when P_c is lower than 58, 62, 71, 78, 80 $ /ton respectively for P_e= 0.06, 0.09, 0.12, 0.15, 0.18 $ /kWh. Carbon capture system (case 2) and combined system (case 3) are optimal options when P_c is higher, when P_c is lower than 38, 50, 63, 80, 90 $ /ton respectively for P_e= 0.06, 0.09, 0.12, 0.15, 0.18 $ /kWh, case 3 is better, or case 2 is better option.

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Biography

Yuting Tan now is a Ph.D. student with research interest in Carbon Capture and Storage (CCS).